Semi-Automated and Interactive Construction of 3D Urban Terrains

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ABSTRACT

We have developed a set of tools that attack the problem of rapid construction of 3D urban terrains containing buildings, roads, trees, and other features. Heretofore, the process of creating such databases has been painstaking, with no integrated set of tools to model individual buildings, apply textures, place objects accurately with respect to other objects, and insert them into a database structure appropriate for real-time display. Since fully automated techniques for routinely building 3D urban environments using machine vision have not yet been entirely successful, our approach has been to build a set of semi-automated tools that support and make efficient a human interpreter, running on a PC under Windows NT. The tools use remote sensing technologies and thus are applicable to the general case of not having close access to urban data (e.g., collections of buildings may be in foreign or hostile environments), but can use close-up image data if provided. Once we have the 3D urban model, we face the problems of final precise alignment of objects and real-time visualization. We attack both problems by providing an interface to VGIS[1], our high-resolution global terrain visualization system. Typically data from different sources, such as phototextures, building models, maps, and terrain elevations, do not register precisely when put together. VGIS provides accurate, real-time display of all these data products. Our tools provide a porting mechanism for bringing the urban data into VGIS where it can be interactively aligned. The data are then organized into a VGIS database for real-time display.

Keywords: urban terrain, visualization, building extraction

1. INTRODUCTION

Visualization of 3D urban terrains is useful for city planning, reconnaissance, real estate development, and a host of other applications. Yet the sheer number of buildings in even a moderately-sized city presents a huge hurdle to the task of building a model suitable for visualization. It is difficult to obtain individual building models in CAD format, and laborious to add phototextures and to simplify these models for use in real-time rendering systems. Individual buildings can be modeled from one or more oblique images, but again this presents a problem when hundreds or thousands of buildings must be generated one at a time. Automatic techniques for detecting buildings in overhead images have been developed in recent years, but are still quite sensitive to image quality. For fast, reliable production of urban terrains, it is better to equip a trained human interpreter with a flexible set of tools for creating detailed individual buildings, for bulk creation of buildings from an overhead image, and for visualization and final geographical placement of the created buildings.

Using our tools, the user first compiles one or more overhead photos of the urban area to be modeled. If close-up oblique images are available for selected buildings, we can use Eos Systems, Inc.'s PhotoModeler™ [2] software to create 3D models photogrammetrically. Remaining buildings are created from one or more overhead images. The user selects roof corners, base corners, and shadow extents, and a building with flat-topped textured roof is created of appropriate height (given the date and time a photo was taken). Building sides can be textured using texture images loaded into a texture library, or extracted from perspective-distorted images. Finally, the building models are exported into VGIS, a real-time 3D landscape visualizer which places the urban terrain in its global setting. Here, final placement and adjustment of the buildings can be performed, and the user can explore and interact with the created urban terrain.

2. OVERHEAD IMAGERY

Crucial to accurate scale and placement of buildings generated using our tools is the quality of the underlying overhead digital imagery. Images must be of sufficiently high resolution to allow the operator to swiftly and precisely select roof corner

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points. Also, to automatically generate the building heights, building shadows must be visible, and the precise time and date the imagery was collected must be known. Lastly, accurate geoplacement of the buildings will depend on the rectification of the overhead image.

2.1. Image Rectification

To accurately place urban structures in their correct position on the Earth's surface, we must ultimately derive correct latitude/longitude for given points in the overhead image. To this end, our software accepts imagery which has been geocorrected using a GIS. Alternatively, there is limited geocorrection capability available in our software if raw overhead imagery is being used. If the user has 3 known reference points, a simple linear transformation can be performed. Alternatively, 2^{nd} or 3^{rd} order transformations are available, if appropriate. It is important that we invest effort at this stage to obtain accurate georeferencing of urban structures, thus sparing ourselves large-scale adjustments once we import the structures into VGIS for final positioning and visualization.

2.2. Time/Date Selection

We recommend that all terrain images used with our tools have a known time and date of creation. Heights for structures which are in the center of the field of view cannot be derived from a single overhead image, and must be found from either time/date + shadow measurement, or from multiple oblique views in PhotoModeler™. Of course, height information can be estimated if the number of stories (floors) is countable, and we estimate a distance per story.

3. BUILDING EXTRACTION

Because we are faced with the problem of creating urban terrains with an uncertain quality and quantity of input imagery, our approach has been to remain as flexible as possible, enabling us to use close-in oblique photos of structures if available, but not relying on this as a requirement. Often, we do not have enough imagery to capture building texture and height from an overhead image. We may also wish to capture from oblique views high resolution building textures not available in our relatively low-resolution overhead images. It is also sometimes necessary to model "marquis" structures in detail, which is best accomplished by deriving 3D structure photogrammetrically from multiple oblique views. We wanted to use existing tools, only developing new tools where no equivalent existed. To that end, detailed building models are created using off-the-shelf PhotoModeler™ software, while bulk building extraction from overhead photos is done using software we have developed, both of which run under Windows NT.

3.1. Photomodeler

Photomodeler Pro™ (Figure 1), from EOS Systems Inc, was chosen for close-in oblique view building extraction. There are a number of photogrammetry software products available for creation of 3D models from one or more photos, but Photomodeler™ was chosen for its' large number of output formats (in our case, Wavefront format was needed), the ability to use complex camera + lens models, if available, or to use a default camera model with a single image, if one image is all that we have. The first step towards modeling a building is input imagery from a camera. Photomodeler™ includes calibration software if we want to use our own camera, or it can estimate camera parameters if the image was taken by an unknown camera type. We then use software tools to find approximate camera positions. Features (points, lines, and simple 3D primitives like cones and cylinders) are marked in one or more oblique images of the structure, and associated between images. We can apply textures to the extracted structure from the image(s) the structure was created from, or we can use arbitrary texture images. At this point, we can create a structure model and view it in a 3D preview window. If it looks good, we export it in Wavefront format. VGIS imports this model, where final placement, rotation, and scaling operations can take place in a 3D world-view setting.

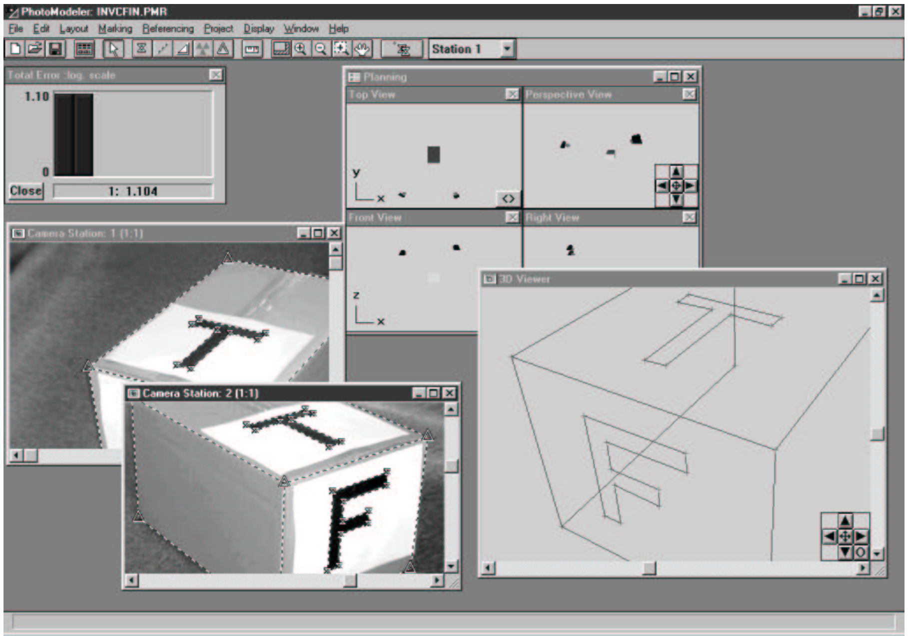

Figure 1: PhotoModeler™ 3D Extraction Demonstration

3.2. Overhead Extraction Software

Rapid construction of urban terrains would be nearly impossible if every building were modeled from multiple oblique views. Overhead imagery must be used to generate many of the buildings in the urban scene. We have developed a project-minded software tool which gives a human interpreter the ability to quickly select buildings, apply textures, create and save/export building models, and visualize created cities using Open GL under Windows NT.

3.2.1. Building Polyhedra Generation

For fast semi-automated building extraction from an overhead photo, we developed software which creates simple user-selected flat-topped polyhedral building objects. It was found that automatic extraction of buildings using edge detection and other methods are prone to failure if the input image resolution and/or building-to-terrain contrast are not of sufficient quality. For rapid building creation, we employ a human interpreter for building corner/base-point/shadow selection. First, we click on each corner of the building roof, then adjust the corners' 2D positions as needed. We then anchor one roof corner to the building base (if the base is visible, i.e. if the building is not in the center of the image) by dragging an anchor line from a roof corner to the associated base corner. This is necessary for correct positioning of the building polyhedron on the surface plane. If a shadow is visible, we drag a shadow line from a roof corner to it's associated shadow corner (Figure 2). At this point, the software has created a building model, correctly placed, with roof texture extracted from the overhead photo (Figure 3). If height has not been assigned (i.e., no shadow was specified, or no date/time was given for the overhead photo), the user may enter a height based on a priori knowledge of the height, estimation from the number of stories visible in the overhead image, or a guess.

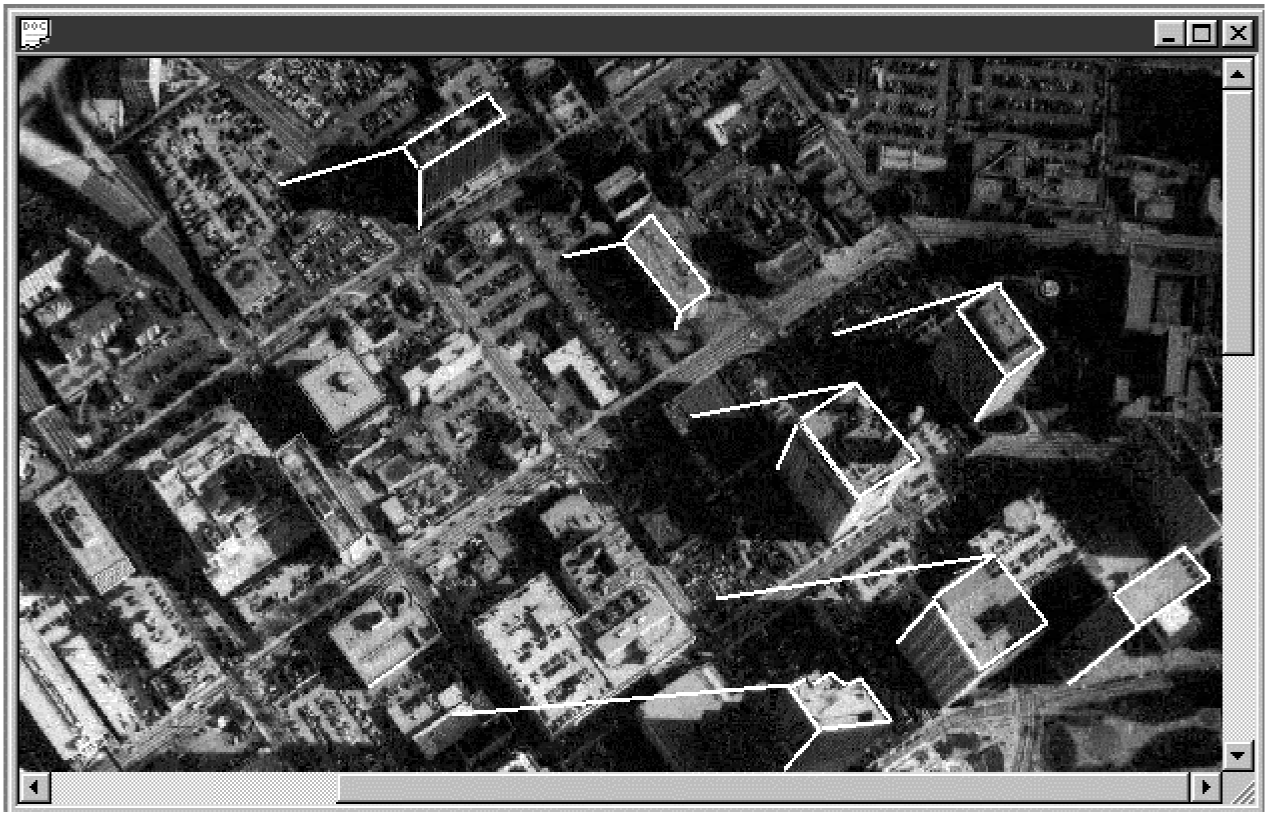

Figure 2: Roof Selection, Anchoring, and Shadow Selection

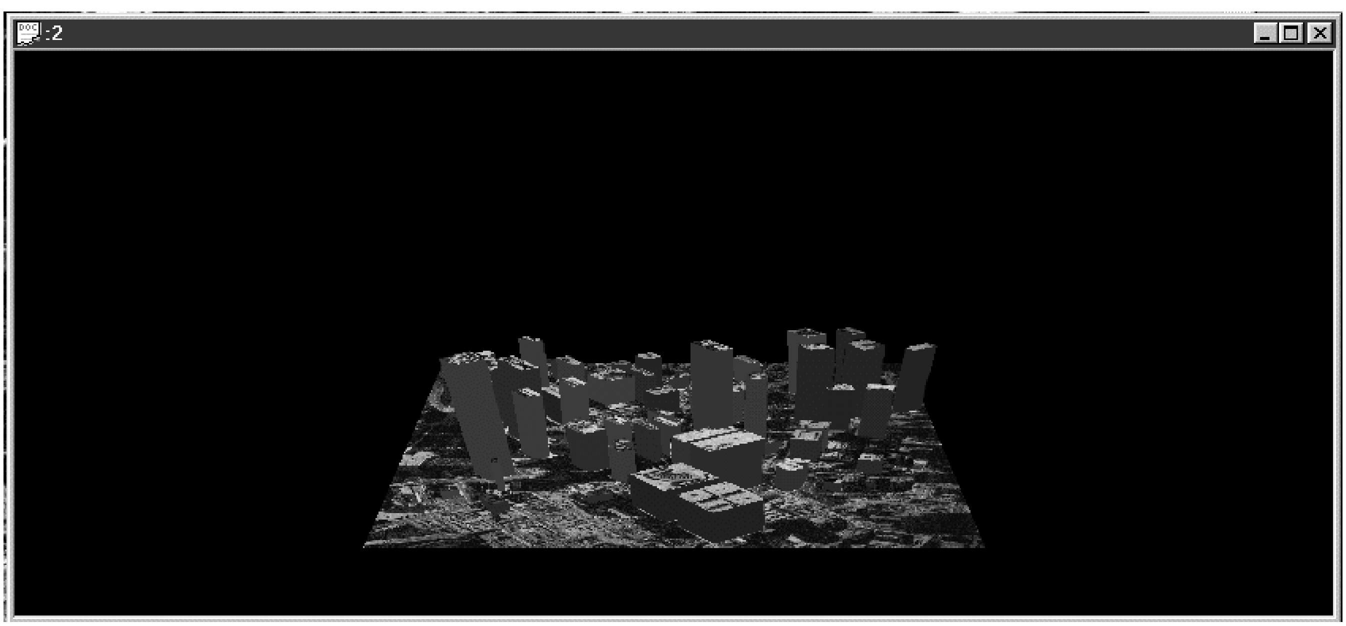

Figure 3: Untextured 3D Urban Terrain Preview Window

3.2.2. Building Textures

The sides of extracted buildings can be issued a single color value, but realism is enhanced if actual building textures are applied. To this end, our extraction software supports texture extraction from oblique imagery (which can be overhead imagery, if the building in question is not in the center of the image and at least one side is visible). Images in Windows BMP, JPEG, or TIFF format are loaded, and selected for texture extraction. The desired texture corners are selected, regardless of perspective distortions in the image. The software then performs a projective mapping[3] (projection from one plane, through a point, onto another plane) of the selected arbitrary quadrilateral to a rectangular texture (Figure 4). This texture will have most of the perspective distortion removed, and will look like the building side as it would appear from an orthogonal view direction (with the exception of protrusive features). Extracted textures are added to a texture library. A thumbnail sheet is available for the user to select from, and apply various textures to one or more buildings at a time (Figure 5). Any arbitrary texture can also be loaded into this library for building application.

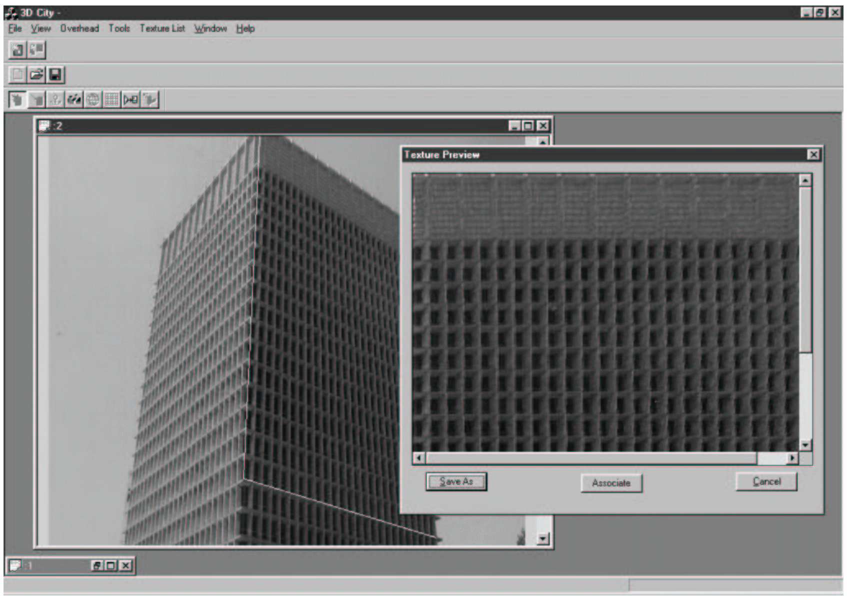

Figure 4: Texture Generation Using Projective Mapping

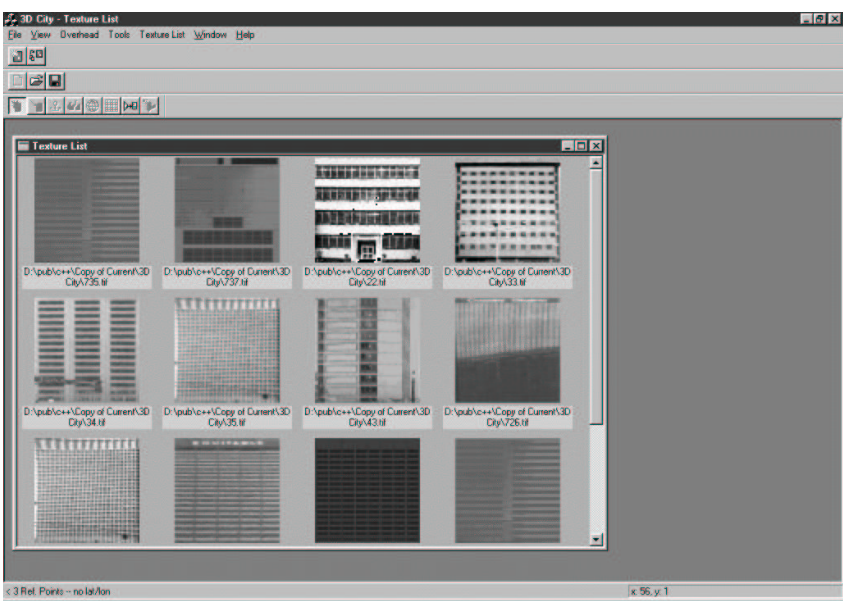

Figure 5: Texture Library Thumbnail Window

3.2.3. City Visualization

The created buildings can be visualized separately, or positioned within the urban terrain, in a 3D-viewing window. The Windows OpenGL library is used to render the textured buildings, with the overhead image used as the underlying terrain base. Zooming, panning, and rotation can be used to inspect every detail of the created city. Actual 3D visualization is often needed for the user to spot height/placement inconsistencies, and adjust these parameters as necessary in the building extraction window (Figure 6).

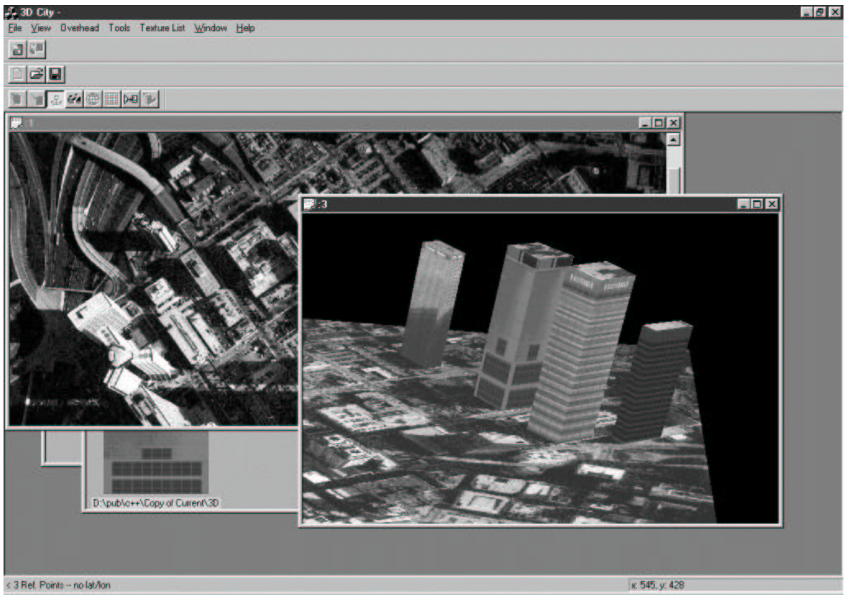

Figure 6: Textured Buildings

3.2.4. Exporting The Urban Terrain

Once the buildings in our urban terrain have been created, we export them using a modified Wavefront format which our visualization tool, VGIS, can import. The baseline ASCII Wavefront format was augmented for our purposes, with the following additions: support for geoplacement (lat/lon coordinates), texture mapping, color selection, and full 3D rotation. VGIS uses these enhancements to correctly place building objects on the terrain.

4. URBAN TERRAIN VISUALIZATION

It is necessary to interact visually with the created urban terrain to correct errors in placement and scale. VGIS is an powerful, immersive visualization tool for exploring virtual landscapes in real time. A unique memory-paging algorithm, coupled to a quadtree-based multiresolution terrain height/image database, allows the user to travel a "virtual Earth." Level-of-detail is changed continuously, so that distant objects and terrain are rendered using simple models (smaller textures + less polygons), while close-in objects are rendered with high detail. This is an ideal environment for our urban terrain visualization, because it allows us to place our city atop properly positioned elevation data & imagery, and to interact with (move, rotate, scale) the buildings once loaded. After final positioning of the buildings on the underlying terrain, the buildings are incorporated into the VGIS object database, which enables real-time visualization through memory paging and level-of-detail (Figures 7 & 8).

Figure 7: Overhead View of Atlanta, VGIS

Figure 8: Oblique View of Atlanta, VGIS

5. CONCLUSIONS

We have developed a Windows NT-based toolset for rapid creation of urban structures from overhead and oblique photos, and for visualization of these created structures. We have shown that a human operator can effectively create a rich 3D urban terrain using a small suite of software tools. This provides the flexibility to handle multiple types of input imagery, and to scale the time invested in creating a building with it's relative importance in the scene. Ongoing improvements include the addition of a roof template library (for application of various roof types to our buildings), a more intuitive user interface for building extraction, enhancements to the level-of-detail algorithms in VGIS (how to represent cities and individual buildings at arbitrary view angles and distances).

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